The Measurement of the Polarized Gluon Distribution Function at PHENIX

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Abstract. One of the goal of the PHENIX experiment is to understand the contribution of the gluon spin to the proton spin. In PHENIX, the polarized gluon distribution is measured by the longitudinal double spin asymmetry of the various probes. Recent results on the measurement of the polarized gluon distribution function with PHENIX experiment are presented.

Keywords: Delta G, Polarized Proton-Proton Collisions, RHIC
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INTRODUCTION

It had been believed that the proton spin is carried by the quark spin. The spin dependent structure function measurements started at SLAC. In 1988, the European Muon Collaboration (EMC) measured spin dependent structure function with higher statistics and in a wider kinematic range, and reported that the contribution of quark spin for proton spin is only $12 \pm 9 \pm 14\%$ [1, 2]. This result is called "Spin Puzzle". Later, other experiments measured the contribution of quark spin for proton and neutron spin and reported consistent results with EMC.

The proton spin consists of the spin of the quarks, the gluons, and the their angular momentum. The proton spin can be written as follows;

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g \tag{1}$$

where $\Delta\Sigma$ and ΔG are quark and gluon contribution spin to the proton spin and L_q and L_g are the orbital angular momentum of quarks and gluons, respectively.

The measurement of the polarized gluon distribution function is important for understanding the origin of the proton spin. The polarized gluon distribution function has been measured by HERMES at DESY using a deep inelastic scattering. The process used is $e + p \rightarrow h^+ h^- X$, where $h = \pi, K$. SMC and COMPASS also reported the results. Another approach to the polarized gluon distribution function is a measurement of the particles which are produced by quark-gluon or gluon-gluon interaction in polarized proton-proton collisions. At RHIC, the gluon distribution function can be measured directly, precisely, and over a large range of gluon momentum fraction with several independent processes. The polarized gluon distribution function can be evaluated from

double spin asymmetry;

$$A_{LL} = \frac{1}{P_1 P_2} \frac{N_{++} - N_{+-}}{N_{++} + N_{+-}} \tag{2}$$

where P_1 and P_2 are the beam polarizations, N_{++} represents the number of observed particles when helicity of beam1 is + and helicity of beam2 is +. N_{+-} represents the number of particles when helicity of beam1 is $+$ and helicity of beam2 is $-$. The A_{LL} can be written to Leading-Order (LO) as follows [3];

$$A_{LL} = \frac{\sum_{f_1,f_2,f} \Delta f_1 \times \Delta f_2 \times \left[d\hat{\sigma}^{f_1 f_2 \to f X'} \hat{a}_{LL}^{f_1 f_2 \to f X'} \right] \times D_f}{\sum_{f_1,f_2,f} f_1 \times f_2 \times \left[d\hat{\sigma}^{f_1 f_2 \to f X'} \right] \times D_f} \tag{3}$$

where Δf_i and f_i $(i = 1,2)$ are polarized and unpolarized parton distribution function. The $\hat{a}_{LL}^{f_1 f_2 \to f X'}$ is the partonic asymmetry for the subprocess $f_1 f_2 \to f X'$ and is calculable with pQCD. The D_f is the fragmentation functions of f. The polarized gluon distribution can be calculated from Equation 2 and Equation 3.

PHENIX EXPERIMENT

The Relativistic Heavy Ion Collider (RHIC) at BNL is operated as the first polarized proton-proton collider in the world with beam energy range from 50 GeV to 250 GeV. In PHENIX, data with an integrated luminosity of 3.8pb^{-1} for longitudinally polarized collisions with 47% average polarization have been collected in the run of year 2005 at $\sqrt{s} = 200$ GeV. It is 40 times larger in figure of merit for A_{LL} than the past year.

The PHENIX detector consists of four instrumented spectrometers and beam detectors [5]. One of the instrumented spectrometers is called Central Arm. The 'Central Arm' consists of tracking chambers (Drift Chamber (DC), Pad Chamber (PC)), particle identification detectors (Ring Imaiging Cerenkov Detector (RICH), Time Expansion Chamber (TEC), Time Of Flight Counter (TOF)) and ElectroMagnetic Calorimeter (EMCal). The Central Arm covers the azimuthal angle of 180° and the pseudo rapidity range from -0.35 to 0.35. Photons with high transverse momentum (p_T) are detected by the EMCal with high p_T trigger. Another one is called the 'Muon Arm'. The Muon Arm consists of Muon Tracker (MuTr) and Muon Identifier (MuID). These arms cover the azimuth angle of 360° and the pseudo rapidity range of $1.2 < |\eta| < 2.4$. The beam detectors are Zero Degree Calorimeter (ZDC), Beam Beam Counters (BBC). The PHENIX Beam Detectors are used to measure the z-vertex to produce the trigger timing and to measure the luminosity in heavy ion and proton-proton collisions. The ZDC is also used as a local polarimeter to monitor the direction of the proton beam polarization.

RECENT RESULTS

In this section, the recent results of PHENIX related to the Δg are reported. There are several probes for the measurement of the Δg in PHENIX. The most precise results of Δg has been given by π^0 production.

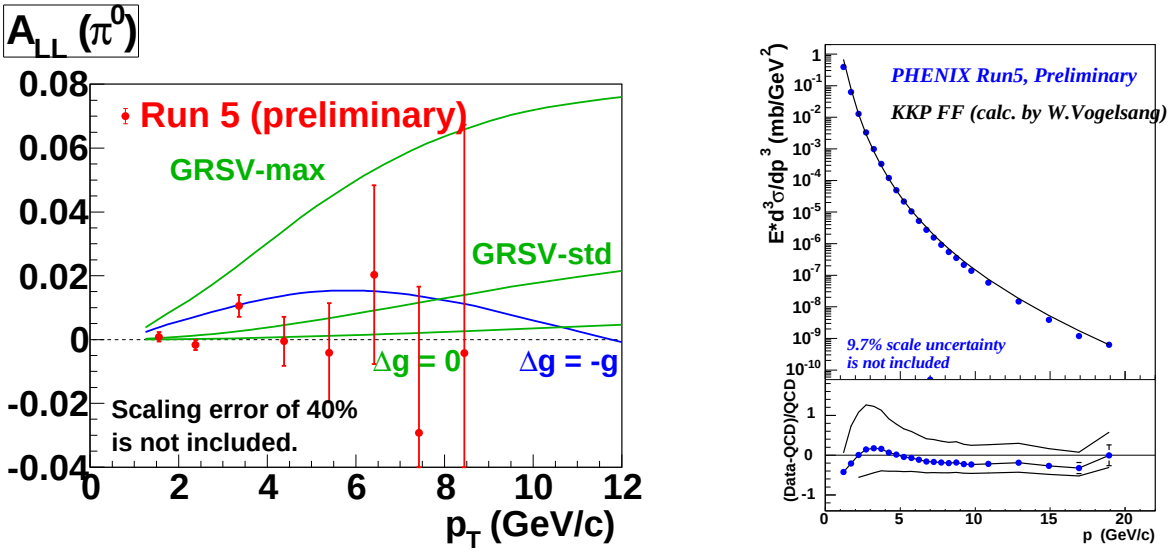

FIGURE 1. Left figure shows A_{LL} in π^0 production measured using 2005 data as a function of p_T with four NLO pQCD calculations for π^0. GRSV-std represents the case of the best fits to the DIS data and other curves are calculated with the input of $\Delta g = g$ (GRSV-max), $\Delta g = 0$ and $\Delta g = -g$ at the input scale of $Q^2 = 0.4\text{GeV}^2$. Right figure shows the comparison of π^0 cross section using 2005 data with pQCD NLO calculation with KKP FF.

Figure 1 (right) shows the cross section for π^0 using 2005 data with with pQCD NLO calculations with KKP fragmentation function. The wide p_T range from 1 GeV/c to 20 GeV/c is covered. The 9 orders of magnitude on the cross section is obtained. pQCD NLO calculation with KKP fragmentation function describes the data well over all measured p_T region.

Figure 1 (left) shows A_{LL} in π^0 production measured using 2005 data as a function of p_T with four NLO pQCD calculations for π^0 [6]. The precision of $A_{LL}^{\pi^0}$ is improved significantly compared with previous year [7, 8] in order to the progress in the accelerator performance. According to the recent result of $A_{LL}^{\pi^0}$, the case of $\Delta g = g$ is rejected. Some theoretical groups has done the QCD fits to the polarized DIS data with our π^0 results [9, 10].

One of the useful channel to study of the gluon polarization is the J/ψ production. J/ψs are predominantly produced through gluon-gluon interaction without fragmentation process at RHIC energy, therefore A_{LL} in J/ψ production is sensitive to gluon polarization. Figure 2 (left) shows the A_{LL} in J/ψ production in year of 2005 with dimuon pairs with the theoretical curve calculated by Color Octet Model (COM) and Color Singlet Model (COS). More precise measurement of J/ψ will be done in the near future with enough statistics.

Jet production is one of the promising probe to study of the gluon polarization. The advantages of jet production are the high statistics comparison with other probes and not affected by fragmentation. Jet is reconstructed by summing of photon energy and momentum of charged particles within a cone with R ($= \sqrt{\phi^2 + \eta^2}$) of 0.3 in the $\eta - \phi$ space. The value of R is determined by detector acceptance. The ratio of the observed p_T

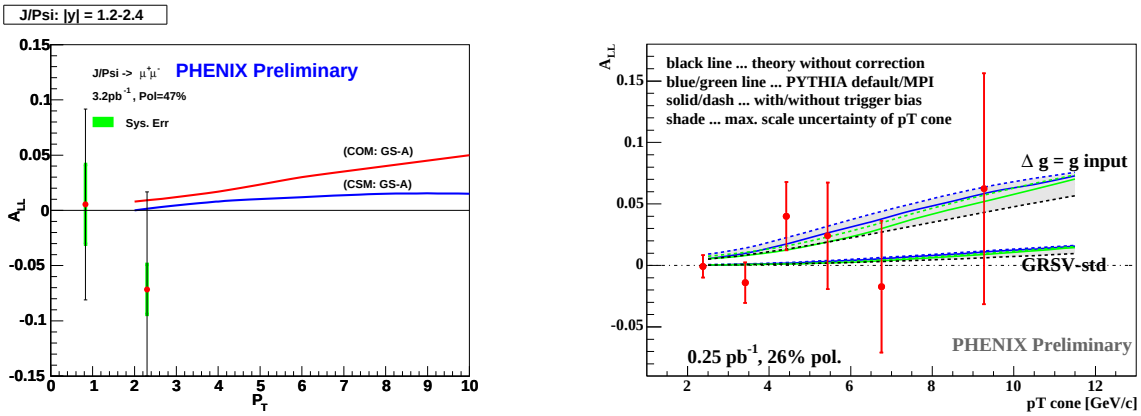

FIGURE 2. Left figure shows the A_{LL} in J/ψ production in year of 2005 with dimuon pairs with the theoretical curve calculated by Color Octet Model (COM) and Color Singlet Model (COS). Right figure shows A_{LL} in jet production as a function of p_T observed by the detector (p_T cone) with two theoretical curves are normalized by the PYTHIA simulation. Black line represents the original curve. Blue represents the scaled by the default PYTHIA. Green represents the scaled by the PYTHIA with the correction of multi-parton interaction. The bias of high energy photon trigger is (not) considered in the solid (dashed) line.

(p_T cone) to the real p_T of initial scattered parton is evaluated by PYTHIA simulation. The ratio is about 80%. Figure 2 (right) shows A_{LL} in jet production as a function of p_T observed by the detector (p_T cone) with two theoretical curves are normalized by the PYTHIA simulation. More precise measurement of jet production will be done in the near future with enough statistics.

Direct photon production is very useful tool of measurement of the gluon polarization. Because the direct photon is produced by parton scattering directly, there is no ambiguity of the fragmentation function. Additionally, direct photon is detected easier than jet because it dose not spread like a jet. A_{LL} in direct photon production can disentangle the sign of Δg due to no gluon-gluon scattering process. On the other hand, the difficulty is its poor statistics compared with other channels. Figure 3 (right) shows the cross section for direct photon using 2003 data with pQCD calculation with CTEQ6M PDF with different scale factor. At this moment, only the cross section is presented and more statistics is need to measure the A_{LL} enough accuracy. The expected A_{LL} with luminosity of 65pb^{-1} and beam polarization of 70% is shown in Figure 3 (left).

SUMMARY

The study of Δg is on going at the RHIC-PHENIX experiment at BNL. RHIC was operated the long spin run in 2005 and 2006 successfully. The latest results are presented here. More precise measurement will be obtained in the near future and determined the sign of Δg by direct photon measurement. Moreover, it is needed to cover wide range of Bjorken x to determine the integral of Δg. Run at $\sqrt{s} = 500$ GeV will be able to reach smaller x region.

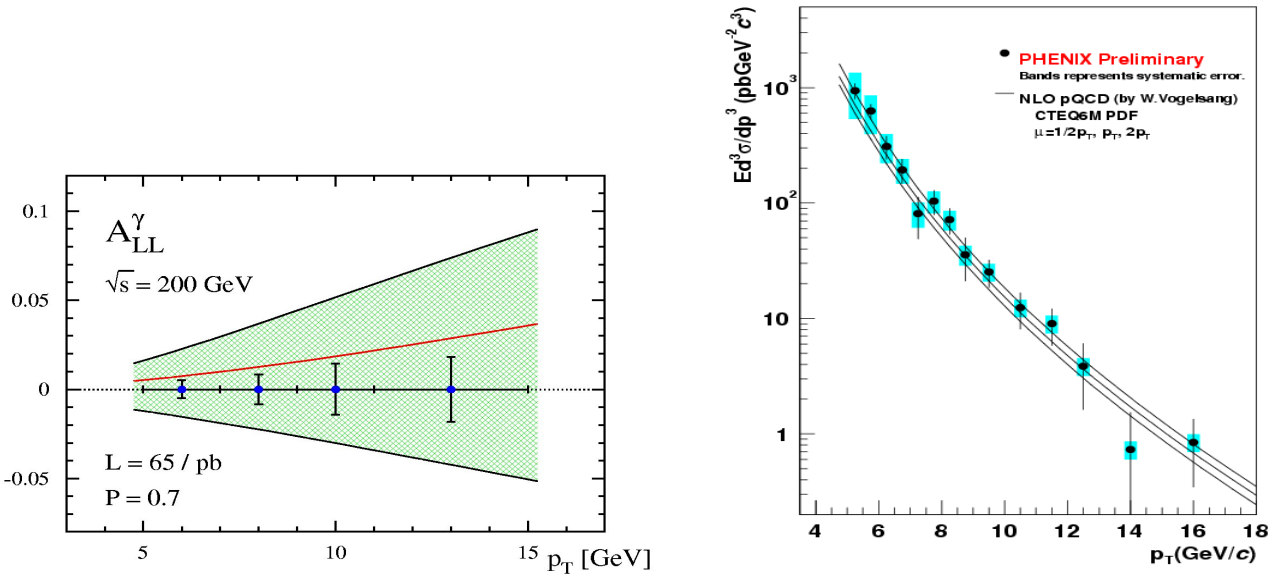

FIGURE 3. Left figure shows the expected A_{LL}^{γ} as a function of p_T with luminosity of 65pb^{-1} and beam polarization of 70% with theoritical curves. Right figure shows the cross section for direct photon using 2003 data with pQCD calculation with CTEQ6M PDF with different scale factor. Top line represents scale factor of $0.5p_T$. Middle line represents scale factor of $1.0p_T$. Bottom line represents scale factor of $2.0p_T$.

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